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Multidomain Noise Attenuation for Multimeasurement Towed Streamer Data

S. Rentsch* (Schlumberger), S. Bodyakin (WesternGeco), L. Polanco Espezua (WesternGeco), A. Özbek (Schlumberger), W.G. Brouwer (WesternGeco) & P. Watterson (WesternGeco)

SUMMARY

Recordings of a multimeasurement towed streamer are subject to several different sources of noise that can negatively impact the useful signal content. Most of the conventional noise attenuation is performed in the shot domain. In this paper, we analyze the behavior of low frequency noise in domains other than the shot domain and exploit the fact that some noise that is coherent in the shot domain turns incoherent in other domains, e.g., the common-offset domain or the common-receiver-point domain. This noise randomization is used to introduce filters that can give a noise reduction of several dB in the low frequencies (< 30 Hz) while preserving signal fidelity. We demonstrate the noise attenuation capabilities on data from a survey carried out in the North Sea.
Introduction

In multimeasurement marine seismic acquisition, one encounters several different sources of noise and sensor perturbations that can negatively impact the useful signal content. As described in Teigen et al. (2012), a towed cable is subject to several modes of vibrations due to water flowing around it. A cable with one or more accelerometer sensors is always sensitive to vibrations in the cable, while hydrophones can be made insensitive to vibrations by design. The strongest noise modes are longitudinal, transversal, and torsional vibrations. Özdemiş et al. (2012) show that “the amplitudes of the vibrations on the accelerometers are typically several orders of magnitude stronger than the corresponding noise recorded by hydrophones at frequencies below about 20 Hz”. It also discloses a multiscale noise attenuation algorithm acting in the shot domain that provides strong noise attenuation for accelerometer data at these frequencies (Figure 1).

However, even after the sophisticated filtering disclosed in Özdemiş et al. (2012), residual low-frequency noise (up to about 15 Hz) can be present on accelerometer data and sometimes even on pressure data. This is particularly visible in Figure 1 on the right. In this paper, we aim to further attenuate this residual noise, exploring two domains different from the shot domain (Figure 2).

A workflow sorting the data into the common-offset domain (COD) and/or to the common-receiver-point domain (CRPD), applying a dip filter, and sorting it back to the shot domain, has been developed that aims to attenuate low-frequency noise while preserving signal and vector fidelity in a multimeasurement towed marine streamer. The latter is of utmost importance for subsequent processing that capitalises on vector information like deghosting, crossline reconstruction, seismic interference detection, and removal among others.

Multidomain noise attenuation (MDNA)

Multidomain noise attenuation explores opportunities in which residual noise that appears to be coherent and inside the F-Kx signal cone in the shot domain is not necessarily coherent and inside the signal cone in other domains, e.g., common-offset or common-receiver-point domain. During the initial noise attenuation workflow described by Özdemiş et al. (2012), noise is already attenuated in the shot domain and virtually no noise is present outside the theoretical signal cone (Figures 3 and 4, left panel). The theoretical signal cone depends on the speed of sound in water which is the order of 1450 m/s but this may vary as some of the main controlling factors are water temperature, salinity and tow depth. Noise that is incoherent from shot to shot will appear in a pseudorandom manner in the common-offset domain as well as the common-receiver-point domain as shown in Figure 3.

Figure 1 Picture taken from Özdemiş et al. (2012) showing filtered pressure data (left) and raw (middle) and filtered vertical component accelerometer data (right).

Figure 2 Domains available for gather building.
This randomization of the noise will map some of the noise outside the theoretical signal cone of $c=725 \text{ m/s}$ in the common-offset and $c=1450 \text{ m/s}$ in the common-receiver-point domain. The effect can be seen in Figure 4 where the part of the spectrum that lies outside the theoretical signal cone is enclosed by solid black lines forming a triangle. The maximum frequency $f_{\text{max}}$ that can lie outside the theoretical signal cone is controlled by the shot spacing $d_s$ for both COD and CRPD and the minimum velocity $c$ at which a horizontal plane wave would travel:

$$f_{\text{max}} = c \cdot k_{\text{Nyquist}},$$

with

$$k_{\text{Nyquist}} = \frac{1}{2 \cdot d_s}.$$  \hfill (2)

For example, at a 25m nominal shot spacing, the maximum frequency would be about 15 Hz in the common-offset domain and about 30 Hz in the common-receiver-point domain. Filters removing the

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1 In the common offset domain 725 m/s is the slowest velocity of signal which corresponds to a purely horizontally travelling wave if the speed of sound in water is 1450 m/s.
noise in the enclosed black triangles shown in Figure 4 act outside the theoretical signal cone and, hence, are assumed to be signal safe. Of course, the steepness of the filter should be chosen in a way not to cause any signal damage at the edges. The theoretical signal cone is straightforward to determine automatically from a minor set of acquisition information like velocity of sound in water and shot spacing. For this reason, noise attenuation based on signal cone dip filtering can be run in an automated manner without extensive user interaction, e.g., in the onboard processing framework. The order of the desired filter will dictate the legacy time for onboard processing. As for any vector data processing, vector fidelity is assured if the same filter is applied to all available dimensions of the vector either subsequently or in a joint manner. The filters as designed and described above are only supposed to remove noise that is outside the theoretical signal cone and, hence, preserve vector fidelity of the signal, but not of the noise if applied only on part of the vector measurement.

MDNA results

The results below are from a survey carried out in the North Sea with an advanced streamer platform that acquired data consisting of pressure as well as vertical particle velocity and crossline particle velocity measurements.

In Figure 5, panels (a) and (f), we show data after shot-domain noise attenuation, but before multidomain noise attenuation in a normal view, and in panels (c) and (h) with a different colour clip. Low-frequency noise coherent in the shot domain is apparent on both measurements, but is not necessarily correlated between them. The noise is still incoherent from shot to shot and can, hence, be attenuated by the proposed method. In Figure 5, panels (b) and (g), we show the noise attenuated data after a one-pass common-offset domain dip filtering process, and again with a boosted colour clip in panels (d) and (i). The removed noise is shown in panels (e) and (j) and we would like to point out that there is only noise present in these panels, corroborating the signal safety of the proposed procedure. We also have encircled some areas in Figure 5 to aid a before and after comparison and appreciate the better signal in the filtered data. The noise removal can be expressed in dB as a
function of frequency by looking at average spectra before and after noise attenuation. We averaged the spectra for all traces over the whole shot line before and after noise attenuation and the results are shown in Figure 6. Very high noise attenuation (up to 5 dB) was achieved in the very low frequencies and good noise attenuation of 1 dB or higher was achieved up to 10 Hz. We highlight once more that signal-safe dip filters in the common-offset domain only act up to 15 Hz in conventional acquisition geometries with 25m shot spacing (Equation (1)). To achieve noise attenuation for higher frequencies, another domain, e.g., the common-receiver-point domain can be used in subsequent or joint filtering processes, or the shot spacing can be reduced to change the Nyquist wavenumber. The latter is probably harder to achieve as there is a lower limit to tow speed as well as a minimum record lengths depending on the target area. We also point out that the amount of noise attenuation depends on how the noise is spread over the frequency range of the acting filters as well as on how randomised it appears in the alternative filtering domains. The more random it is, the more it will map outside the theoretical signal cone and, hence, the more can be removed safely.

Conclusions

In this paper, we introduced multidomain noise attenuation (MDNA) for a towed multimeasurement streamer and prove its uplift using data from a survey carried out in the North Sea. The noise attenuation workflow is specifically designed to minimize the presence of low-frequency noise in a signal-safe and vector-signal-fidelity-preserving manner. We demonstrated that, even using only one domain other than the shot domain, one can achieve noise reduction of several dB in the low frequencies.

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References
